EYE-MOVEMENTS DURING 'RETINAL RIVALRY'

By

Robert H. Peckham

A Dissertation

Submitted to the Board of University Studies of the
Johns Hopkins University in Conformity with the
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By ROBERT H. PECKHAM, Temple University

The present study was undertaken because the phenomenon of retinal rivalry, although frequently investigated, has never been subjected to a detailed study of the movements of the eyes during its occurrence. No one knows definitely whether eye-movements are made when the eyes become temporarily anoptic (either completely for their whole pattern, or only partially with respect to some detail) nor whether the movement, if it does occur, is sufficiently large to displace the image into the periphery. If the image is peripherally displaced, the explanation of rivalry becomes a simple matter. If it is not, present speculations regarding the functional processes of the central nervous system obtain an added degree of plausibility. Moreover, eye-movements, even if too small to displace the image from the macula, might induce anopsia. It is obviously important to find out how the eyes behave during these perceptual variations. It can be observed that when a subject traces an outline figure in a stereoscope with a stylus—where the image for one eye is complete and the other partial —that the act of tracing produces partial anopsia at the region of the stylus-point. It is therefore important to find out what happens to the fixation processes at this moment. Also, the relative effects on rivalry when tracing in a pseudoscope instead of a stereoscope should be studied.

Helmholtz listed three stimulus-conditions of retinal rivalry.[1] They are: (a) when the visual fields are different but homogeneous; (b) when only one field contains non-homogeneous elements; and (c) when both fields contain non-homogeneous elements. When such fields are presented stereoscopically, "sometimes there will be alternations, so that, where for a while only parts of one image were visible, presently parts of the other image will emerge and suppress portions of the first image. . . . This fluctuation, in which parts of the two images mutually supplant each other, either side by side, or one after the other, is what is usually meant by rivalry between the visual globes."[2] It is under condition (c) that rivalry is most marked. Helmholtz explained the phenomenon in terms of attention, concluding "(a) that man possesses the faculty of perceiving these images in each eye separately, without being disturbed by those in the other eye, provided it is possible for him . . . to *concentrate his whole attention* on the objects in this one field; . . . (b) the content of each separate field comes to the consciousness without being fused with that of the

* Accepted for publication August 16, 1934. From the Psychological Laboratory of Johns Hopkins University.

[1] H. Helmholtz, *Physiological Optics,* English trans., 3, 1924, 493 ff.

[2] *Ibid.,* 494.

other field by means of organic mechanism; and that therefore, the fusion of the two fields into one common image, when it does occur, is a psychic act."[3]

Like those of Helmholtz, subsequent investigations of the phenomenon of 'retinal rivalry' have been exclusively subjective, and of the many conclusions drawn and theories proposed, none have been founded upon objective data. Although these descriptive essays are interesting in their delineation of the many aspects of the problem, they are not essential to the present discussion.

Preliminary Experiments

Our purpose in the preliminary experiments was twofold: (a) to delimit the conditions necessary for the appearance of 'retinal rivalry'; and (b) to determine what apparatus would be required in a more exhaustive study.

Apparatus. The apparatus used was an enlarged Brewster stereoscope.[4] In this modification of a familiar apparatus, a pair of plus spheres was set before the field

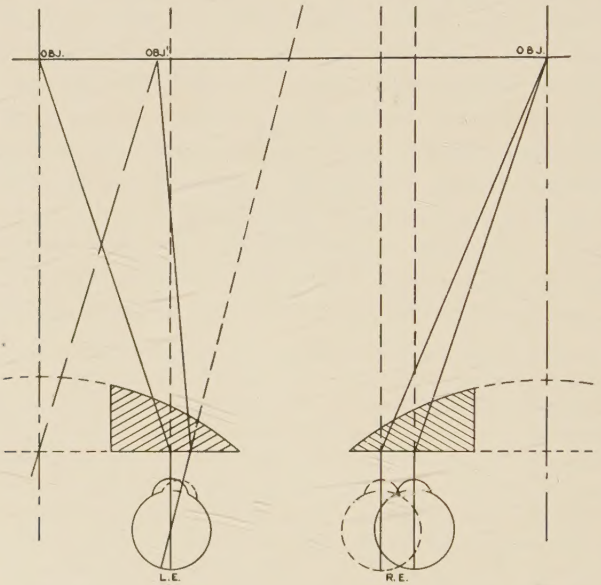


Fig. 1. Brewster Stereoscope as Adapted for Ophthalmic Needs
Obj. = Object Obj.' = Deviated object

of the instrument so that their focal length was equivalent to their distance from the field. Their optical centers were separated by an arbitrary distance of 170 mm. Zero marks were placed on the field with the same separation. Light coming from a zero point will be refracted by the lens to infinity. Further, any beam of light from this point, passing through any given point in the lens, will be likewise refracted,

[3] *Ibid.*, 499.

[4] D. Brewster, Law of visible position in single and binocular vision, etc., *Edinb. Phil. Trans.*, 15, 1844; also, *Phil. Mag.*, 24, 1844, 356-439.

neglecting spherical aberration. Any beam from a source off this point, in the plane of the field, upon refraction will leave the lens with the same angle to the optical axis as the principal ray from this point had before refraction.

Thus an eye, as in Fig. 1, can be placed in any position behind this lens, and yet must be directed straight ahead, parallel to the optical axis, in order that the image fall upon the fovea. Light from a point off the center mark will be so refracted as to require the eye to turn in its direction, through the same angle that its principal ray makes with the axis, in order that the fovea be below its respective image. Conversely, an eye which deviates will require that light, to fall upon its fovea, must come from a point in the field deviating in such a manner as to make its principal ray parallel to the angular deviation of the eye from the optical axis of the lens. The field was marked in rectilinear coördinates of one prism diopter each. The lenses were set in a sliding head-piece providing changes in focus, and the field was mounted upon an adequate support to permit comfort and stability in the use of the instrument.

Procedure. Two yellow cards, one with a round spot 1.3 cm. in diam. and the other with a black square of the same size, were placed before the left and right

FIG. 2. SHOWING "BALL-BAT" DESIGN AND THE TYPICAL RESULT

eyes respectively. The black square was placed on the zero or center mark of the field. With both of his hands in the visual fields, *S* was required to move the red spot so that it appeared to be directly above the black square—"like a red golf ball on a black tee." This same test was repeated for the other hand and eye.

After determining the "phoric" conditions of *S* in this manner,[5] it was next desired to ascertain some condition of rivalry which could be sufficiently controlled. As already stated, "attention to novel elements" in the stimulus-pattern for one eye will tend to bring that eye and its pattern into dominance. When we asked *S* to trace a pattern, which was presented to one eye, on the empty field before the other eye, the blank area surrounding the stylus perceptually dominated the pattern, for a short period of time.

The design used in the preliminary experiments was a crude picture of a ball-bat, with the lines 2 mm. wide (Fig. 2). This contour was chosen because it was simple and easy to talk about, enabling *S* to report his perceptual changes with less confusion. In order to produce both rivalry and fusion, thus at once delimiting the rivalry-producing conditions and maintaining some control over the eye-movements, the lower ¾ of the ball bat was removed on one side. Two cards were used, one imprinted with the complete ball bat, and the other with the uppermost portion

[5] This procedure, called the "phoria test," is a modification of ophthalmic practice. It should be included in any form of stereoscopic investigation, because of its importance in establishing proper convergence.

of the bat only. Rivalry was introduced by requiring *S* to trace, with his stylus, the outline of the bat on the card that contained only a partial contour. The complete picture was set in the zero position, and the incomplete picture at the phoric deviation measured for that eye. *S* was requested to make any necessary change in

TABLE I

RÉSUMÉ OF THE RESULTS OF THE PRELIMINARY EXPERIMENTS

S	Records	Total time (sec.)	No. of disap.	Av. time of disap. (sec.)	Av. no. of disap. per sec.	
					R.H. L.E.	L.H. R.E.
1	R-1	27.2	3	.82	.110	
	R-2	22.8	2	.55	.087	
	R-1, 2	50.0	5	.68	.100	
	L-1	34.1	7	.87		.205
	L-2	28.2	7	.46		.248
	L-1, 2	62.3	14	.66		.225
	R2-1, 4	106.8	14	.80	.131	
	L2-1, 4	116.3	25	1.09		.202
2	R-1, 3	163.1	27	1.47	.165	
	L-1, 3	128.5	20	1.20		.156
3	R-1, 3	69.9	11	1.98	.157	
	L-1, 3	60.5	9	.95		.147
4	R-1, 3	124.9	26	.42	.213	
	L-1, 3	69.2	18	.82		.254
5	R-1, 4	103.8	15	.39	.142	
	L-1, 4	127.9	34	.98		.230
6	R-1, 3	107.6	13	1.91	.120	
	L-1, 4	141.1	28	1.64		.195
7	R-1, 3	52.8	15	1.39	.284	
	L-1, 5	55.6	14	1.94		.250
8	R-1, 3	68.5	13	1.20	.191	
	L-1, 3	48.4	2	.55		.034
9	R-1, 3	62.0	11	1.75	.175	
	L-1, 3	169.5	37	2.08		.209
10	R-1, 3	173.1	23	2.24	.131	
	L-1, 3	128.6	16	1.82		.131
11	R-1, 3	89.3	10	1.32	.104	
	L-1, 3	98.4	14	1.09		.132
12	R-1, 3	117.7	19	2.21	.162	
	L-1, 3	112.9	16	1.75		.139
13	R-1, 3	81.2	21	.87	.218	
	L-1, 3	85.5	23	1.19		.265
Totals	89		491			
Av.		31.3	5.5	1.29	.174	.183

this position for comfortable 'fusion' of the two objects. A simple spring key, similar to a telegraph-key, was supplied to the other hand in a convenient position. *S* was given a few trials in recording rivalry as manifested by the partial or total disappearance of the object pattern. When such a disappearance occurred he was to press down on his key, and stop tracing until the image returned. No attempt was made to record the disappearances of the stylus, since on only four occasions such disappearances were reported. The most common disappearance was that a portion of the pattern would fade away for a few millimeters above and below the

stylus-point, and would stay away for several seconds. Upon return of the object-perception around this small area, the tracing was continued until the next disappearance. No record was taken of the particular part of the ball-bat that disappeared, since no area or section seemed to disappear more often than any other. A typical description of the disappearance is shown in Fig. 2.

The silent contact key was set in series with the pen of a Cambridge three-pen ink-recorder. A metronome, beating half-seconds, controlled another pen. A record of the beginning and end of each cycle of tracing was made by *E* with the third pen.

Results. First, we shall study the records of 'disappearances.' These records demonstrate the existence and frequency of the phenomenon. Then

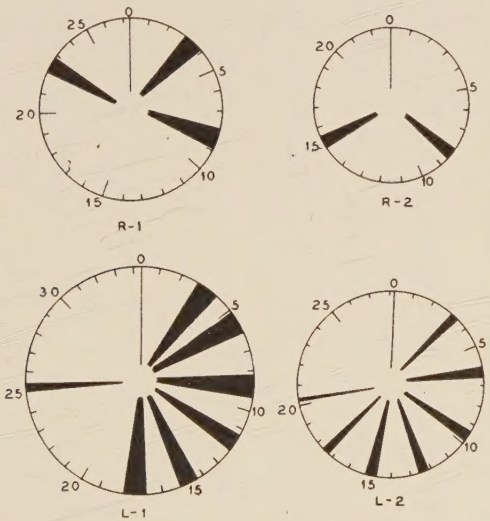


FIG. 3. TEMPORAL SEQUENCE OF DISAPPEARANCES OF *S* 1
Circumference represents total time.

we shall turn our attention to more intimate studies with *S*s 1, 9, and 13. Then we shall be prepared to discuss the apparatus and procedure to be used in a more extensive study. We consider first the results of *S* 1. His preliminary records are presented in detail. The record contains two trials with the right hand and two with the left. *S* was right-handed, as judged from tests in tapping speed, mirror writing and tracing, and general habitual use. Table I gives us the total time for every trial for *S* 1, and the totals of the times for the right and the left trials for the other *S*s. We find, from the italicized items, that *S* 1 reported three disappearances during his first (R-1) tracing, which occupied him for 27.2 sec. The average length of these disappearances was 0.82 sec. During the

TABLE II

THE GROSS RESULTS OF THE EXPERIMENTS WITH THE STEREOSCOPE

Condition	S	Records from the right field					Records from the left field				
		No. trials	Time (sec.)	Disappear.	Eye-move.	Correspond.	No. trials	Time (sec.)	Disappear.	Eye-move.	Correspond.
Tracing & Pattern-Eye	B	3	30	2	6	1	3	47	9	17	6
	C	2	79	8	21	5					
	D	3	61	5	5	1	4	93	4	18	0
	E	3	129	16	44	11					
	F	4	46	5	10	3	4	42	5	16	5
	G	3	141	15	30	11	3	107	13	33	9
	H	3	79	24	21	8	3	87	22	32	15
	I	5	103	21	28	15	7	186	37	45	22
	J	1	18	3	6	1	2	29	9	14	7
	K	2	226	26	50	15	1	149	23	44	16
	M	4	74	14	22	9	3	102	17	27	14
	N	3	50	7	9	6					
	O	3	127	32	25	6	2	103	22	31	17
	P	3	53	8	20	7	3	46	9	16	4
	R	2	77	9	14	6	2	122	14	25	8
	S	2	26	4	10	4	3	36	6	12	1
	T	3	155	16	31	8	2	97	11	19	8
	U	4	50	8	14	4	4	81	8	15	4
	V	3	68	8	27	7	3	77	10	22	8
	W	3	135	20	20	7	2	96	9	19	8
	X	3	129	18	19	6	3	131	39	36	18
	Totals:	62	1856	269	432	141	54	1631	267	441	170
	R+L	116	3487	536	873	311					
Tracing & Tracing-Eye	B	3	32	3	10	1	3	40	7	12	4
	C	2	71	12	9	3					
	D	3	51	3	4	0	2	29	2	3	0
	E	2	76	8	12	5					
	F	2	20	3	5	1	2	19	3	5	1
	G	3	163	23	34	10	3	116	19	31	13
	H	3	76	22	21	14	3	69	22	21	12
	I	4	76	13	14	8	6	109	18	31	13
	J	2	31	7	4	2					
	K	1	72	10	14	5					
	M	2	42	6	4	3	3	78	15	21	3
	N	3	55	8	10	6					
	O	2	73	15	13	6	2	83	14	18	12
	P	2	37	3	9	2	3	50	9	15	7
	R	1	54	9	17	8	2	95	13	14	7
	S	2	20	3	11	2	3	40	11	13	6
	T	3	214	28	37	13	2	72	7	9	2
	U	3	48	7	12	3	1	18	2	4	1
	V	3	71	7	20	6	3	74	11	19	11
	W	3	121	16	3	2	1	29	2	1	0
	X	2	65	13	10	6	3	129	39	26	13
	Totals:	51	1468	219	273	106	42	1050	194	243	105
	R+L	93	2518	413	516	211					

TABLE II (*Continued*)

THE GROSS RESULTS OF THE EXPERIMENTS WITH THE STEREOSCOPE

Conditions	S	Records from the right field					Records from the left field				
		No. trials	Time (sec.)	Disap-pear.	Eye-move.	Corre-spond.	No. trials	Time (sec.)	Disap-pear.	Eye-move.	Corre-spond.
Without Tracing & Pattern-Eye	C	1	55	13	16	6	1	51	11	13	5
	F	1	45	4	13	4	1	63	5	10	2
	I	1	54	7	4	0	1	70	11	7	3
	K	1	61	6	13	4	1	49	6	11	3
	N	2	65	14	22	9	2	93	14	28	10
	R	1	70	7	10	2	1	41	3	7	1
	S	1	40	3	39	3	1	42	7	28	5
	V	1	25	2	7	1	1	23	4	9	3
	Totals:	9	415	56	124	29	9	432	61	113	32
	R+L	18	847	117	237	61					
Without Tracing & Tracing-Eye	C	1	69	12	19	7	1	55	16	13	6
	F	1	52	3	15	1	1	62	3	13	1
	I	1	70	11	9	5	1	71	9	10	3
	K	1	47	6	9	5	1	75	9	15	2
	N	2	109	29	30	23					
	R	1	46	5	10	2	1	49	6	7	3
	S	1	64	10	72	10	1	32	4	22	3
	V	1	22	3	8	2	1	22	5	9	3
	Totals:	9	541	79	172	55	7	366	52	89	21
	R+L	16	907	131	261	76					

two right hand tracings (R-1, 2) he has reported a total of 5 disappearances in 50 sec. of tracing, or 0.1 disappearances per sec. These disappearances were mediated through the left eye, hence the caption R.H.–L.E. (Right Hand-Left Eye). Fig. 3 shows these relations plotted on a circle. The circumference of the circle represents total time, and the shaded sectors the periods of disappearance. There were a greater number of disappearances when using the left hand to trace than when using the right, and the total time for the left hand was longer. The average disappearance for the right hand was 0.92 and 0.55 sec. for the first two trials, and for the left hand 0.87 and 0.46 sec. The disappearances were more frequent and shorter in duration for the left hand for this *S*.

The original records of all the *S*s are similar to those of *S* 1. It is impossible to find consistent temporal or spacial sequence of the disappearances in the results of any of our *S*s. There is one possible exception. At the joinings of the complete and partial picture, in tracing from the top around, counter-clockwise, there is a faded area which may or may not develop into a disappearance, and which is comparable to the fluctuating gray iridescence spoken of by Helmholtz at the intersection of two wide

black bars in a stereoscope, one vertical and one horizontal.[6] The *Ss* were warned to distinguish between this incomplete fading and complete disappearance.

Since there is nothing else of value in the detailed data beyond its distribution, and since this distribution is in itself too irregular for any generalized treatment, the data of this preliminary work have been summarized in Table I. Rather than include each trial the data have been grouped as

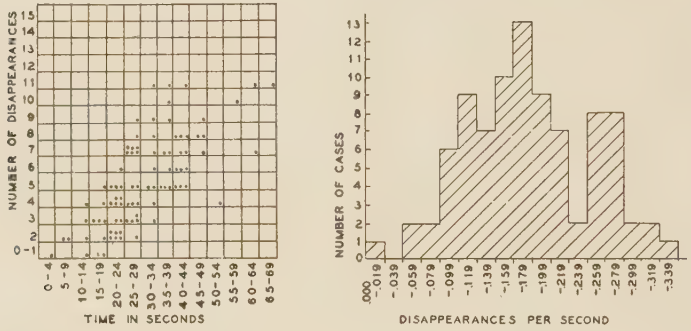


FIG. 4. SHOWING SCATTER AND DISTRIBUTION OF THE RESULTS OF THE PRELIMINARY EXPERIMENT

shown for *S* 1. The total time for the trials, the number of disappearances, the average time per disappearance, and the average number of disappearances are given. It is seen that the disappearances are about as variable in frequency as they are in spacial and temporal sequence. In comparing the even and odd trials, in the original data, this variability was quite marked.

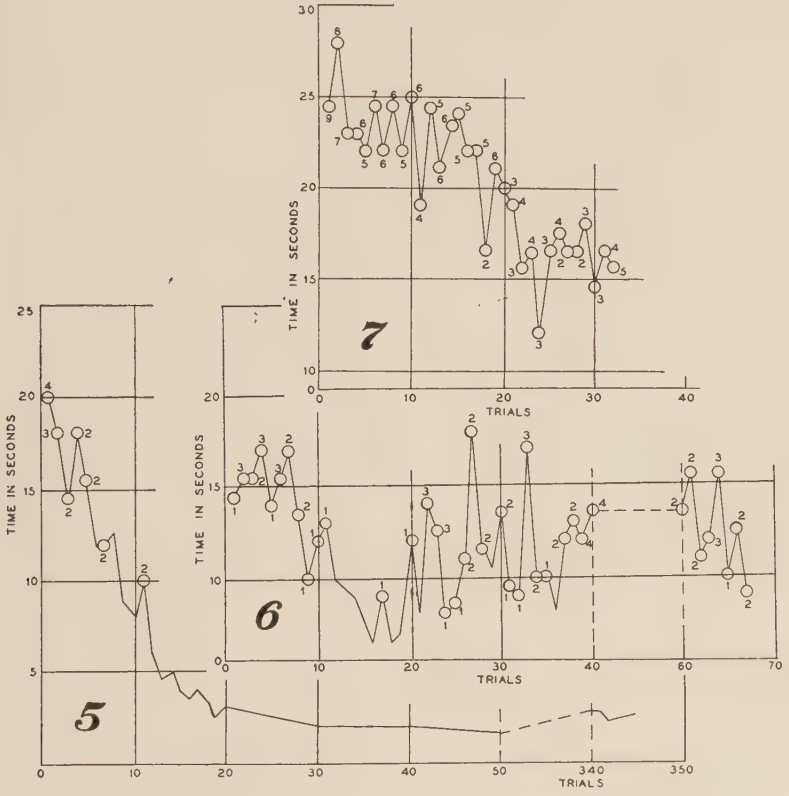
To examine the character of the disappearances, the measures shown in the last two columns of Table II were computed. The time for a tracing and the number of disappearances were to a certain extent mutually variable. *S* had been told to trace slowly, but no definite speed was required. He was, however, told to wait until the disappearances were over before continuing his tracing. Thus more time was consumed when the number of disappearances increased. But when we examine these columns, we find that the number of disappearances per sec. did not follow such a definite proportionality. Hence, the two variables, total time and frequency of disappearances, were not exactly interdependent.

In order to show by some graphical method the interrelations between the two items, Fig. 4 was drawn. The greater the concentration of these items into a line, the nearer a perfect correlation we might expect a

[6] *Op. cit.*, 496.

large group to show. The greater the divergence (scatter) of these items, the lower will be the correlation in a large group.

We find the semblance of a fair positive correlation. We next examine the number of disappearances reduced to units of one second. This score is recognized by the writer to be artificial, it represents only the numerical



FIGS. 5-7. PRACTICE CURVES OF 3 *Ss*
Fig. 5 shows results of *S* 1; Fig. 6, of *S* 9, and Fig. 7, of *S* 13.

quotient of the number of disappearances divided by the time of tracing. It is, however, a definite score of frequency of disappearances from *S* to *S*. If this frequency were regular, within narrow limits, we should conclude that the disappearances are manifestations of a constant tendency in stereoscopic vision—but we do not find this to be the case.

In estimating the differences between right and left hand tracing, from the average number of disappearances for each tracing, we find no reliable

difference. There is a slight tendency for the *Ss* to report more disappearances with the left hand tracing. This may be due to the fact that left hand tracing, being harder, is slower. It is more interesting to examine the individual records. *Ss* 1, 4, 5, 6, 9, 11, and 13 show more frequent disappearances when the left hand is tracing. *Ss* 2, 3, 7, 8, and 12 show

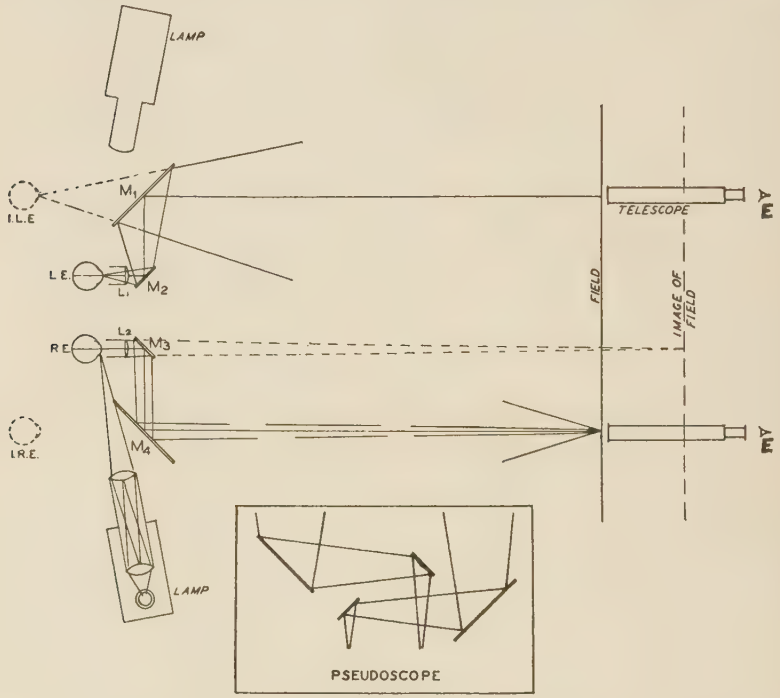


FIG. 8. PLAN OF THE APPARATUS AS VIEWED FROM ABOVE

R.E. = *S*'s right eye
L.E. = *S*'s left eye
L_1, L_2 = Lenses
I.R.E. = Image of *S*'s right eye
I.L.E. = Image of *S*'s left eye
M_1, M_2, M_3, M_4 = Mirrors
E = Experimenter

greater frequency with right hand tracing. All of these *Ss* verbally reported right-handedness. We have found, thus far, that the particular stimulus-pattern used could arouse a form of binocular rivalry in 13 *Ss* selected only in so far that none were grossly pathologic. We have found that the disappearances were real in the sense that the *Ss* could understand instructions concerning them and could record them. We have found that they varied numerically, spacially, and temporally among the *Ss* and among the records of any one *S*. We have found certain limits in these

variations. We have, in short, succeeded in delimiting the problem so that more accurate investigation could follow.

Since it appeared immediately that the situation was not constant, it became necessary to investigate the learning possibilities involved. If the phenomenon were only temporary, we could not expect to make any ex-

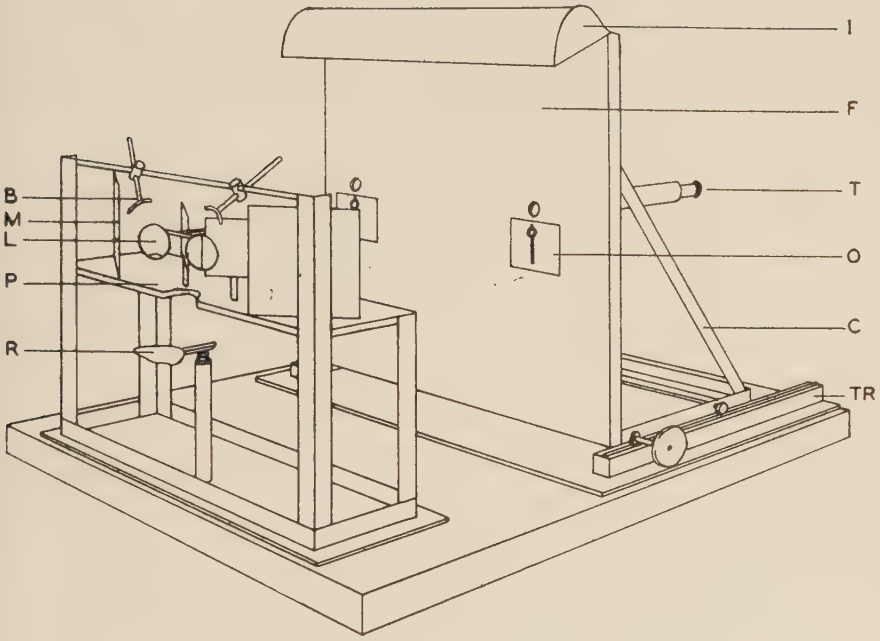


FIG. 9. OUTLINE DRAWING OF THE APPARATUS

B = Brow rest
L = Lens
R = Chin rest
T = Telescope
C = Field carriage
M = Mirror
P = Mirror plate
I = Field illuminant
O = Object
TR = Track for carriage

tensive measurements upon any one *S*. Therefore *S*s 1, 9, and 13 undertook a longer training series. These were continued until it became apparent that there were definite indications of learning, or that no changes were taking place. The three practice curves (Figs. 5, 6, and 7) show the manner of this change. As before noted, the phenomenon is quite individual in character. *S* 1 reported only a few disappearances, and after 11 trials these have virtually disappeared. They appeared again near the end of the record and may have been induced by fatigue. The curve of *S* 9

shows no changes attributable to learning, while *S* 13 shows slight improvement in time and disappearances in 32 trials.

It is evident that subsequent investigation may be safely carried through but a few trials at a given sitting. In the main experiment we have taken our records on different days to avoid training the rivalry away. We are therefore unavoidably exposed to the danger that the causative factors which we are attempting to determine may change in themselves between sessions of recording. This danger was more imaginary than real, since the records showed the frequency of the disappearance varied more from tracing to tracing than from day to day.

Main Experiments

Having determined in the preliminary investigation the conditions and procedure, we sought in the main experiments to determine: (1) whether eye-movements accompanied the rivalry; and (2) whether any relation existed between hand and eye influencing the frequency or character of the disappearances.

Apparatus. Since the Brewster type of stereoscope was not adaptable to the requirements of the present problem, a modified form of Helmholtz's telestereoscope was designed with the following features:[7] optically accurate; adaptable to the pupillary separation of *S;* provision for observing eye-movements; provision for illumination of *S*'s eyes; constant illumination of the field; adequate support of the *S*'s head; proper supporting table; a set of silent spring contact keys for obtaining polygraph records; and a means for changing the stereoscope into a pseudoscope.[8]

The instrument incorporated a method of directly observing eye-behavior by the use of laboratory telescopes. They were directed upon the iris markings near the limbus of *S*'s eyes. To illuminate the eyes, a beam of condensed light was projected tangentially on the cornea. In this manner the iris was illuminated on the outside directly, and upon the inner (nasal) side by virtue of the refractive power of the cornea. The minimum of light entered the eye directly while *S* fixated the test-objects. The illumination of the field was accomplished by two 25-watt tungsten filament tubular bulbs in a reflector. To convert the stereoscope into a pseudoscope, the mirrors, on their posts, were changed to other positions. The mirror-posts were held in place, in either position, by removable taper pins.

The telescopes had a magnifying power of seven diameters. The separation of the objects at the field was 200 mm. The optical distance from the field to *S*'s eyes was 50 cms. The maximum error of the stereoscope (due to undetected variations in the position of *S*'s head, and to maladjustment of the optical parts) was at worst 0.25 mm. at the field, which amounts to an angular error of 17′ 5″. The

[7] *Op. cit.*, 311.

[8] All of these requirements were accomplished with the help of Dr. W. C. Beasley, who also suggested mounting the instrument upon soapstone, since this would prevent loss of accuracy through warping of the metal parts.

least measurable eye-movement that was not ambiguous to *E* was about 0.1 mm. at the cornea. (This is equivalent to about ½° of ocular rotation.)

A four-pen polygraph was used, driven by a shunt-wound motor. The time line was controlled by a seconds pendulum. One pen was used by *E* to record observed movements, one by *S* to record disappearances, and one by *E* to indicate the terminations of each record. Figs. 8 and 9 illustrate the completed stereoscope.

Procedure. In the investigation we wished to determine: (1) whether eye-movements accompanied disappearances; (2) if so, whether they preceded or followed the disappearance; and (3) whether there was any correlation between handedness and disappearances. Testing methods for the determination of these relations had to be developed.

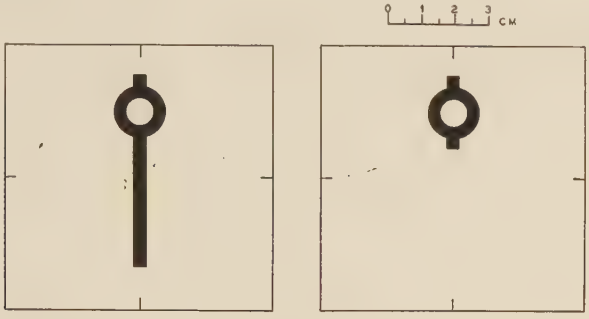


FIG. 10. SHOWING OBJECT THAT WAS TRACED IN MAIN EXPERIMENT

A phoria test was made in the stereoscope and in the pseudoscope. The same test objects and procedure as in the preliminary experiments were repeated.

S was then presented with the test objects shown in Fig. 10. These consisted of a black ring 1.5 cm. outside diam. and 0.8 cm. inside diam. with a vertical bar extending 4 mm. upward from the outer edge and 40 mm. downward from the lower edge. One of these objects was purposely incomplete, the lower bar extending only 4 mm. These pictures were placed in the phoric position, *S* moving them about until they were 'fused.'

He was then instructed to trace the figure with the blackened point of a stylus. He did this tracing on the side of the incomplete figure. After one trial, he was asked to report verbally what had occurred. The tracing was repeated, until he understood what was meant by *E*'s description of "part of the tail fading out, near the pencil." He was then asked to place his free hand on the recording key, and press, then release, the key when part or all of the tail disappeared. These instructions were given verbally, with help and demonstration on the part of *E*.

This study is not, however, open to the criticism of suggesting disappearances. The disappearances were reported spontaneously by *S*, and it was not until he had reported them that the final procedure was demonstrated.

While *S* was tracing, *E* was observing eye-movements through the telescope. and 'Pattern-eye' in the subsequent data. The records for every *S* included six for each hand in each situation. Of these, three of the first included movements of the right eye and three of the left eye. The time required for the first session was about one hour.

TABLE III

THE GROSS RESULTS OF THE EXPERIMENTS WITH THE PSEUDOSCOPE

Condition	S	Records from the right field					Records from the left field				
		No. trials	Time (sec.)	Disappear.	Eye-move.	Correspond.	No. trials	Time (sec.)	Disappear.	Eye-move.	Correspond
Tracing & Pattern-Eye	C	1	31	5	9	4	1	30	6	9	4
	F	2	17	3	5	1	2	31	5	13	2
	G	2	27	6	8	0	2	33	9	16	6
	H	2	54	5	11	4	2	55	10	6	2
	I	2	18	2	2	0	2	17	2	4	1
	M	2	61	9	22	7	2	67	10	20	7
	N	1	9	0	4	0	2	22	3	5	1
	O	2	75	11	17	5	2	59	10	19	6
	R	2	91	15	11	2	2	101	14	7	4
	S	2	31	9	9	2	2	17	1	9	0
	T	2	48	4	2	0	2	91	8	9	2
	U	2	53	5	16	4	2	67	8	27	5
	V	2	55	8	18	4	2	47	10	20	8
	W	2	37	6	4	1	2	37	4	4	1
	X	2	110	20	24	10	2	97	17	25	5
	Totals:	28	717	108	162	44	29	771	117	193	54
	R+L	57	1488	225	355	98					
Tracing & Tracing-Eye	C	1	27	5	6	2	1	38	9	12	3
	F	2	17	2	5	1	2	20	2	5	1
	G	2	21	6	5	1	2	29	7	9	5
	H	2	40	8	8	3	2	60	9	6	2
	I	2	17	3	2	1	2	18	3	1	1
	M	2	85	8	18	7	2	58	8	24	4
	N	1	9	2	2	1	1	22	3	9	2
	O	2	82	10	30	6	2	97	14	40	6
	R	2	58	12	7	4	2	88	14	7	3
	S	2	29	4	8	3	2	22	0	11	0
	T	2	26	1	0	0	2	46	3	3	1
	U	2	71	6	21	5	2	72	5	29	2
	V	2	50	7	16	5	2	55	12	15	5
	W	2	38	7	5	3	2	77	10	9	3
	X	2	106	27	29	20	2	86	18	30	9
	Totals:	28	676	108	172	62	28	788	117	210	47
	R+L	56	1464	225	382	109					
Without Tracing & Pattern-Eye	C	1	42	8	6	3	1	30	7	8	2
	F	1	42	3	15	2	1	39	3	15	2
	G	1	51	4	16	3	1	56	8	17	6
	H	1	57	5	13	0	1	56	15	20	8
	I	1	48	2	8	1	1	40	9	9	4
	M	1	48	9	23	6	1	67	7	45	4
	N	1	11	0	2	0	1	57	6	22	5
	O	1	51	8	12	7	1	50	8	16	5
	R	1	56	3	9	1	1	48	3	2	0
	S	1	49	2	21	2	1	49	9	43	9
	T	1	43	5	1	1	1	36	3	4	1
	U	1	47	3	13	2	1	52	5	14	2
	V	1	31	3	11	1	1	24	6	8	5
	W	1	31	5	8	2	1	24	6	8	5
	X	1	44	11	11	7	1	25	6	15	2
	Totals:	15	651	71	169	38	15	653	101	246	60
	R+L	30	1304	172	415	98					

TABLE III (*Continued*)

THE GROSS RESULTS OF THE EXPERIMENTS WITH THE PSEUDOSCOPE

Conditions: Without Tracing & Tracing-Eye

S	Records from the right field					Records from the left field				
	No. trials	Time (sec.)	Disap-pear.	Eye-move.	Corre-spond.	No. trials	Time (sec.)	Disap-pear.	Eye-move.	Corre-spond.
C	1	39	6	7	2	1	26	6	9	0
F	1	64	4	29	2	1	30	3	9	2
G	1	51	5	16	4	1	40	6	13	3
H	1	45	4	7	0	1	65	15	12	6
I	1	50	5	14	3	1	29	7	8	4
M	1	54	8	32	6	1	40	4	19	4
N	1	17	1	12	1	1	56	7	7	2
O	1	47	7	11	5	1	45	6	18	5
R	1	63	7	5	1	1	53	6	7	1
S	1	66	3	25	3	1	50	6	41	6
T	1	47	3	2	0	1	25	2	1	0
U	1	37	2	12	1	1	55	6	19	3
V	1	46	2	18	0	1	19	6	7	3
W	1	47	9	11	3	1	36	8	7	3
X	1	51	13	13	7	1	38	7	13	3
Totals:	15	677	79	223	38	15	607	95	190	45
R+L	30	1284	174	413	83					

Vertical movements were not recorded, since these were made in following the tracing. All horizontal movements were recorded.[9]

Records were taken with both hands, both eyes, and both apparatuses—the stereoscope and pseudoscope. Since one eye was watching the tracing hand, and the other the vertical bar of the complete pattern, these eyes are labeled 'Tracing-'

A second series added a control evident after the analysis of the first records. For this reason many of the *S*s' records are not complete. The procedure of the first series was repeated without tracing, to check against the criticism that the disappearances were not related to what is usually meant by 'retinal rivalry' but were produced by the act of tracing. This second session consumed about ½ hr.

The third session was the investigation of the disappearances with the pseudoscope. In this case the tracing hand was on the opposite side from the tracing eye, and disappearances of the pattern were mediated through the eye on the same side as the tracing hand. The time necessary was about one hour.

Treatment of data. It was impossible to obtain all of the *S*s for all 3 sittings. There was a total of 574 tests made upon the 24 *S*s. The *S*s' records yielded frequency of disappearance and *E*'s records yielded frequency of eye-movement. These data are shown in Table II for the stereoscope and in Table III for the pseudoscope. As a statistical measure of the reliability, we have computed the coefficient of correlation of the frequency of disappearance in the odd versus the even trials, yielding $+0.60 \pm .06$.

In considering the scattergram of Fig. 11, we are interested in knowing if any sort of numerical correspondence existed between movements and disappearances. From the form of the scatter, apparently they varied in direct proportion. Since this

[9] The horizontal movements were quick deviations from side to side. Most were convergent with divergent return to fixation. No accurate estimate was attempted of the size of the movements. All amounted to ½° or more of rotation.

does indicate what may be a positive correlation had more subjects been used, the writer constructed the frequency histograms of Fig. 12. Since the two curves are so much alike, we are tempted to conclude that a causal relationship exists between fixation (as shown by movements) and 'retinal rivalry,' as shown by disappearances. To test this hypothesis we must know what temporal relationships exist in the data.

We must know whether the movements precede the disappearances, or the dis-

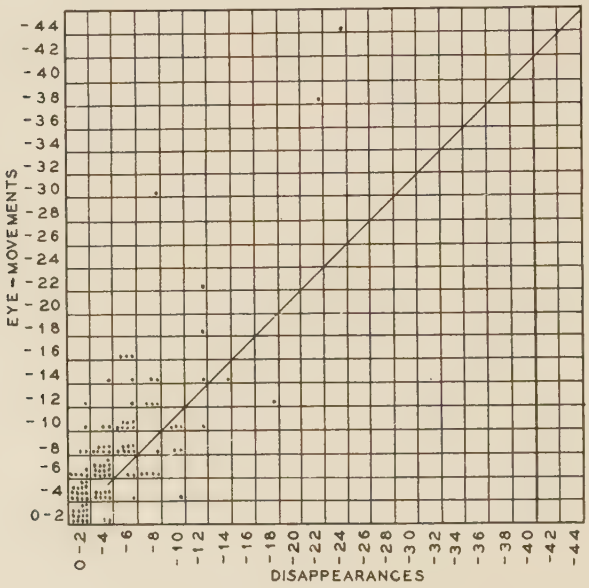


FIG. 11. SCATTERGRAM SHOWING THE RELATION BETWEEN EYE-MOVEMENTS AND DISAPPEARANCES

appearances the movements. We have, therefore, gathered the movements and disappearances which corresponded within an arbitrary time limit. The limit chosen was one second either way. If a movement preceded or followed a disappearance by one second or less, the two are chosen as a corresponding pair. By varying the time limit the degree of temporal causation could be determined, provided such a gathering of items showed positive correspondence beyond that of chance with two independent variables.

One second was chosen as the limit because a longer time (*e.g.* 1.5 sec.) found many disappearances corresponding to one movement. This means that the temporal causation, if it existed, was within a smaller time limit. An attempt to use a smaller time limit (0.5 sec.) showed very little correspondence at all. If there were temporal relations between the two, that relation was not existent in as short a period. An attempt to establish the relation by determining the time between each disappearance and the following (or preceding) movement was obviously a failure, so diverse were the intervals between a given disappearance and the next movement.

Results. There were 1993 disappearances reported in the three series. 3452 records of eye-movements were made by *E* during these disappearances. Of these, 1047 pairs corresponded (*i.e.* $\pm$ 1 sec). In order to better visualize and discuss the nature of this correspondence, the records have been summated into groups and these are graphically illustrated. In studying them, the reader is warned to avoid confusing the definitions

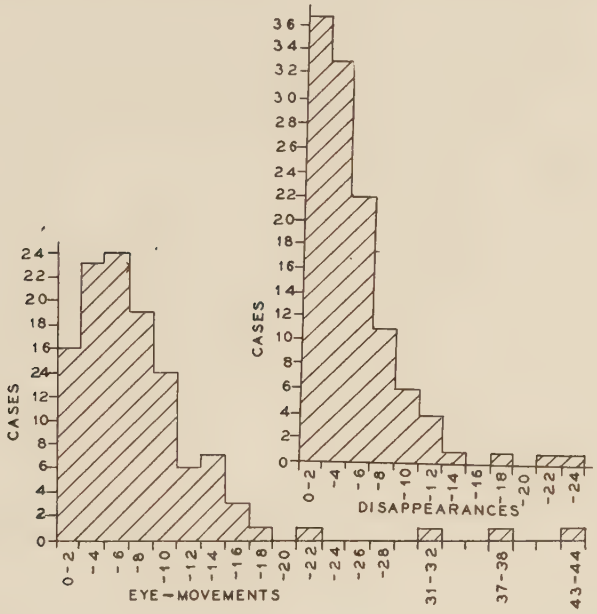


FIG. 12. HISTOGRAMS OF THE EYE-MOVEMENTS AND DISAPPEARANCES

of 'pattern-' and 'tracing-eye' already given. During the experiments where no actual tracing was being done (*i.e.* Series 2), the same system has been applied, and 'tracing-eye' refers to the eye that would have done the tracing.

In the tabulations of Tables II and III, we find listed the cases in which corresponding pairs were found within 1 sec. in either direction. If an exact correspondence existed, there would be no difference between the number of disappearances and the number of movements. Since such a difference is demonstrable, Fig. 13 is included to illustrate this divergence. By using lines whose length is proportional to the total number of movements or disappearances observed, and by representing the corresponding pairs by the overlapping of the lines, it can be shown that there was a

mutual distribution similar to that due to the chance interference of two independent variables. The differences in the total lengths of these figures lie in the number of records of the various types taken rather than to any peculiarities inherent to the situation.

We found in every case that there were as many or more movements that did not correspond to disappearances as there were that did, and in

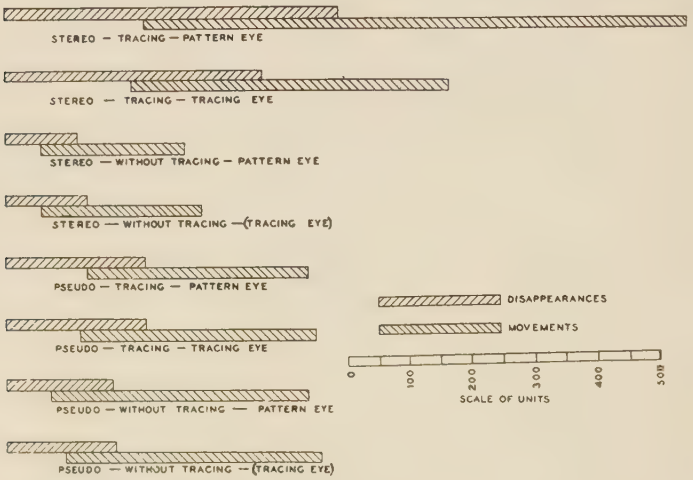


FIG. 13. GRAPHIC ILLUSTRATION OF THE CORRELATION IN EVERY EXPERIMENTAL CONDITION BETWEEN THE DISAPPEARANCES AND EYE-MOVEMENTS

most cases that over half the disappearances were without corresponding movements. To insist that eye-movements and disappearances correspond, is to contend that well over half the movements and half the disappearances were missed in our records. Considering the care involved in the instrumentation and investigation, the writer does not feel that such a contention can be justified.

It might be, however, that eye-movements occurred twice for every disappearance: once at the beginning and once at the end. Were this the case, half the records of movements would have no meaning, since the termination of the disappearance was not recorded by *S*. It would mean that half the records of movements would be temporally related to the records of disappearances, and that there would be approximately twice as many movements as disappearances recorded. There was no such regularity indicated in the records as would be evident if the movements and the beginnings of the disappearances were temporally related in this fashion.

Further, in 8 out of 9 situations, more than twice as many eye-movements were observed as disappearances reported. This relation obtains even if the movements of the 'pattern eye' alone are considered.

If the movements bore a causal relationship to the disappearances, there would be no movements in the 'tracing eye' (save the vertical following movements in both eyes). Since we do find such movements and since neither set, for the 'pattern-' nor for the 'tracing-eyes,' shows a temporal

TABLE IV

FREQUENCY OF DISAPPEARANCES PER 100 SEC.

Apparatus	Eye	Tracing	Without tracing
Stereoscope	pattern	15.3	13.8
	tracing	15.4	15.5
Pseudoscope	pattern	15.5	13.2
	tracing	15.5	13.2

relation for the movements, it follows that the disappearances were independent of the movements. We must determine what other correlations can be found in the data. Were there any effects that might be ascribed: (1) to the act of tracing; (2) to the retinal image of the tracing hand and stylus; or (3) to the difference between the two retinal images when there was no tracing?

The data must be reduced to comparative units, and therefore the fre-

TABLE V

FREQUENCY OF MOVEMENTS PER 100 SEC.

Apparatus	Eye	Tracing	Without tracing
Stereoscope	pattern	24.8	28.0
	tracing	19.2	30.9
Pseudoscope	pattern	24.5	30.3
	tracing	26.7	30.3

quency of disappearances or eye-movements per 100 sec. has been computed. Because of the divergencies in individual differences, we have preferred to average the results and to emphasize the qualitative differences.

Table IV shows the consistent tendency for the frequency of disappearances to maintain constant level during tracing, and for this level to decrease when there was no tracing. The fact that the act of tracing has increased the frequency of disappearance is important. The effect of tracing in the stereoscope has been to increase the rate of retinal rivalry.

We find an anomaly in one case in which the rivalry has not been decreased although there was no tracing. Since there was no effective stimu-

lus change to *S* when *E* was watching either pattern or tracing eye, and since the same condition does not repeat itself in the (effectively identical) pseudoscopic situation, the anomaly remains explainable only in the fact that the sample was so small.

In the same manner the differences in the frequency of movements are demonstrated in Table V. We observe that the frequency of eye-movements was greater without tracing, although without the act of tracing, the frequency of disappearances was smaller. The effect of tracing is therefore to decrease the eye-movements, and to decrease them more on the side of the hand which is tracing. In the stereoscope there were fewer eye-movements per 100 sec. in the tracing eye—the eye on the same side as the tracing hand. In the pseudoscope the reduction is greater in the pattern eye—again the eye on the same side as the tracing hand.

There are two effective stimulus-patterns involved in the tracing, these are: (1) the kinaesthetic pattern due to the movement of the hand; and (2) the visual pattern of this hand moving in the field of view. In the stereoscope these two response-patterns were on the same side, and in the pseudoscope on the opposite side. We find both of these were effective in reducing eye-movements. We find them most effective when they were on the same side of the body. When on opposite sides, we find the kinaesthetic pattern was more effective than the visual pattern.

If attention is defined in terms of vividness or as the proportion of sensory clearness depending upon some particular stimulus-pattern, in this case the field of view in which the tracing occurs, we may say that the act of tracing arouses more attention to this field, increasing rivalry (thus itself an aspect of attention) and decreasing the eye-movements, resulting in increased visual efficiency during the period considered.

From the point of view of 'gradients' we might conjecture that the visual and kinaesthetic gradients when united are effective in reducing eye-movements, but when paired against each other, the kinaesthetic gradient is dominant or more effective than the visual gradient.

Summary

(1) A form of retinal rivalry that can be examined spacially and temporally was defined. This consisted of a vertical bar on one pair of pictures to be used in a stereoscope, the other picture being blank on the corresponding area. To maintain binocular fusion identical parts were included in both pictures.

(2) The rivalry that became manifest with this design took the form of disappearance of a portion of the vertical bar.

(3) When the image of the bar was traced with a stylus on the blank side the rivalry became more pronounced.

(4) In preliminary experiments it was found that with practice the rivalry would disappear.

(5) For the main experiments a large stereoscope of the double mirror type was built. This could be changed at will into a double mirror pseudoscope. Telescopes were incorporated for observing eye-movements.

(6) Using the large stereoscope, simultaneous records of frequencies of disappearance and eye-movements were made.

(7) No relations, causal or temporal, were found between eye-movements and rivalry as manifested by disappearances.

(8) The act of tracing was found to (a) increase the rivalry; and (b) decrease the frequency of eye-movements.

(9) The kinaesthetic pattern involved in the moving of the hand during the tracing was found to be more effective than the visual pattern of the hand moving in reducing eye-movements. This was demonstrated by the difference between the stereoscopic and the pseudoscopic results.

Vita

Robert H. Peckham was born in Youngstown, Ohio, on March 15, 1908. He received his primary and secondary school education in Yonkers, New York, and Waterbury, Connecticut. He received the degree of Bachelor of Arts, majoring in Biology and Physics, from the University of Rochester in 1930, being awarded the first Wile prize for proficiency in Biology in 1927. He was employed by the Bausch and Lomb Optical Company of Rochester, New York, in their Scientific Bureau during the three summer months of 1930. He entered the Johns Hopkins University as a graduate student in Psychology in September 1930. He has been awarded a fellowship for the year 1933-34 by the National Research Council. Division of Anthropology and Psychology.